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CLIMATE AND FOREST FIRES IN MONTANA AND NORTHERN IDAHO, 1909 TO 1919.

By J. A. LARSEN, Forest Examiner, and C. C. DELAVAN, Fire Assistant.

[Priest River Forest Experiment Station, Idaho, 1920.]

INTRODUCTION.

The present report is a result of the study of the relation between climate and forest fires in Montana and northern Idaho. This region is designated as District I of the United States Forest Service. The data used are the weather records of the United States Weather Bureau for the regular and cooperative stations, and the detail fire reports of the United States Forest Service for the years 1909 to 1919, inclusive. Mr. C. C. Delavan has compiled the fire records and Mr. J. A. Larsen the weather data.

The splendid forests of western Montana and northern Idaho have, according to oral and visible records, always been subject to destructive fires. During the last 11 years the seriousness of the forest fire situation has been brought home by the fact that nearly 5,000,000 acres of land burned over in District I, with a total estimated damage to standing timber of over $28,000,000 and a total outlay in fire prevention and suppression of about four and one-half million dollars. This great destruction is gnawing at the vitals of the national timber supply.

By far the greater percentage of this damage has been visited upon Idaho and western Montana. This has been somewhat difficult to understand, especially since Idaho and western Montana show a greater annual precipitation than the sections farther east. The reasons underlying this should be understood so that methods of suppression and means of prevention may be guided by whatever information is obtainable.

It is the plan of this work to investigate the topographic and climatic causes for forest fires in the district generally and in Idaho in particular; to analyze the records of fires and climate for different years for a better understanding of the kind of season which results in bad forest fires; to study the records of fires and weather for individual months to see how much rainfall is needed to allay these fires; to set forth especially dangerous fire weather, the length and intensity of the fire season in the different sections under consideration; to examine the climatic

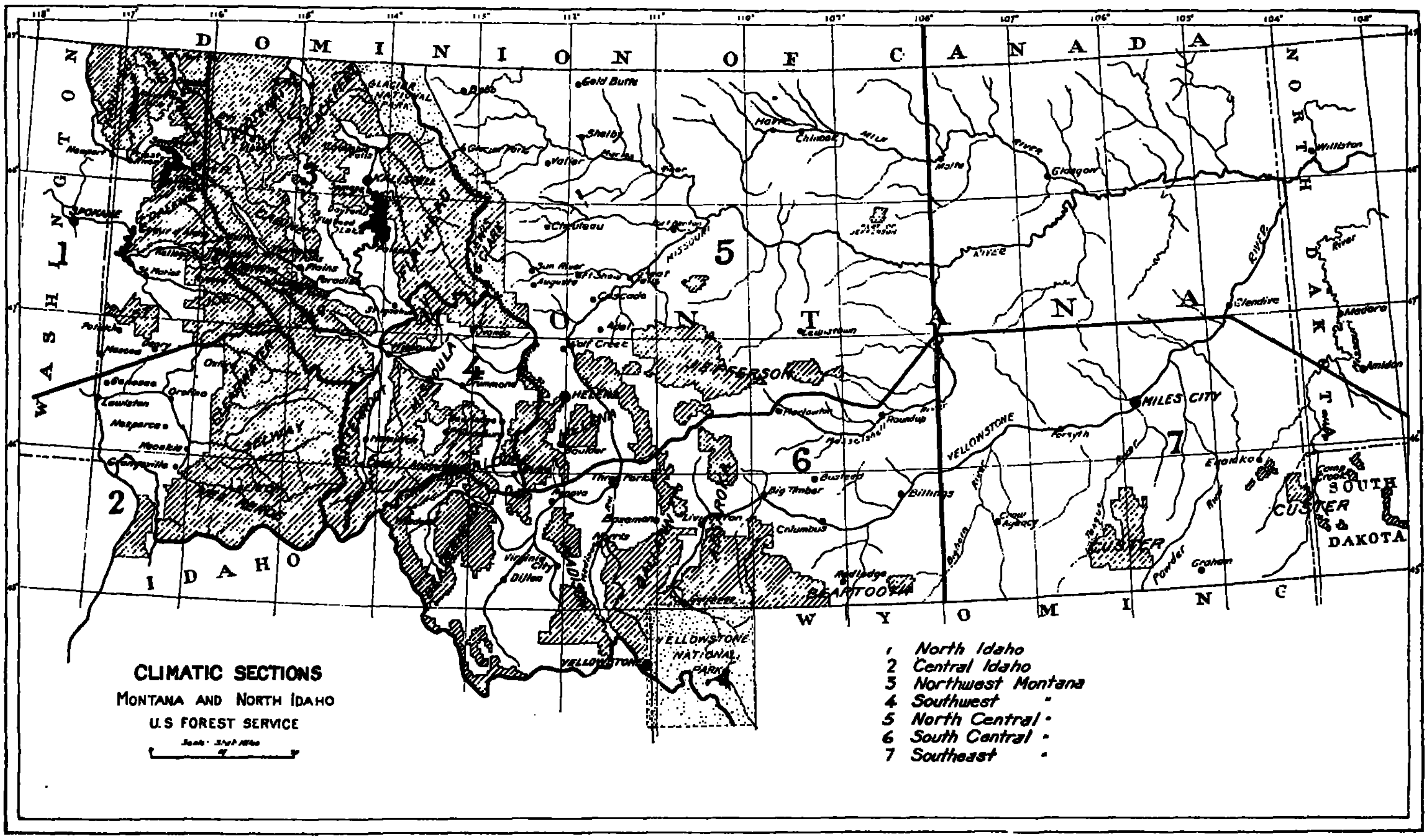

FIG 1.—Climatic sections of Montana and north Idaho.

(To face p. 55)

PLATE 1.—Dense forest of western white pine, western red cedar, and western hemlock, in northern Idaho. The dense under story of hemlock and cedar burns readily and carries the flames into the crowns of the trees.

PLATE 2.—The forest devasted by fire.

records for the last 40 years in order to discover whether or not the last three years are usual or unusual, and to discuss the chances of predicting very dangerous fire weather.

BROAD TOPOGRAPHIC CONTROLS OF CLIMATE AND FOREST DISTRIBUTION.

The region under discussion embraces three broad topographic divisions, as follows: (1) Idaho, north of the Salmon River, where the land rises gradually from 3,000 feet elevation of the Columbia River Plateau to the crests of the Bitterroot Divide, at from 6,000 to 7,000 feet elevation. The lower parts of the forest are composed mainly of western yellow pine and Douglas fir, the intermediate slope has western white pine, western larch, Douglas fir, western hemlock, western red cedar, and grand fir; (2) western Montana, which includes the land between the Bitterroot and the Continental Divides. In this part the elevations vary from 3,000 to 10,000 feet, and from prairies and forests of western yellow pine in the valley through forests of Douglas fir, western larch, lodgepole pine, Engelmann spruce, and alpine fir at the higher points; (3) that part of Montana which lies east of the Continental Divide. This embraces the eastern slopes of the Rocky Mountains, the elevated country surrounding the Yellowstone Park region and the broken topography in southeastern Montana. The forests consist mainly of Douglas fir, lodgepole pine, Engelmann spruce. In southeast Montana there is only western yellow pine.

The forests of Idaho contain a greater variety of species more understory of inflammable cedar, hemlock, and white fur and much more dead and down material than those in the other divisions. In fact, the forests east of the Continental Divide are, except for dense young lodgepole thickets and Alpine fir, quite free from understory, and those in southeastern Montana are of pure yellow pine and, except for patches of dense advance growth, quite open with the characteristic grasses and sedges. Central Idaho, northwest Montana, and the forests surrounding the Yellowstone Park region in south central Montana are most mountainous and difficult of access.

In this study the data for weather and forest fires have been averaged by groups of national forests. These groups are seven in number and conform roughly to separate watersheds. (See Fig. 1 and Table 1.)

TABLE 1.—*Climatic sections of Montana and north Idaho National Forests and weather stations used.*

Divisions.	Groups of national forests.	Weather station.	Elevation (feet).	Years recorded to 1918.
(1) North Idaho.	Pend Oreille	Porthill	1,665	29
	Kaniksu	Bonners Ferry	2,429	8
	Coeur d'Alene	Sandpoint	2,100	8
	St. Joe	Priest River	2,300	8 to 1906
		Priest River Experiment Station.	2,360	7
		Lakeview	2,250	18 to 1915
		Coeur d'Alene	2,157	24
		St. Maries	2,155	19
		Murray	1,750	15 to 1908
		Kellogg	2,305	14
		Burke	4,082	9
		Wallace	2,770	10
		Avery	2,500	5
(2) Central Idaho.	Clearwater	Moscow	2,748	26(1912-15)
	Selway	Lewiston	757	25
	Nezperce	Deary	2,854	4
		Orofino	1,027	14
		French Gulch	4,000	5
		Kooskia	1,261	10
		Musselshell	3,171	5
		Nezperce	3,082	9
		Oxford	3,735	4
		Potlatch	2,550	3
		St. Michaels Priory	4,000	6
		Elk City	5,756	5

TABLE 1.—*Climatic sections of Montana and north Idaho National Forests and weather sections used*—Continued.

Divisions.	Groups of national forests.	Weather stations.	Elevation (feet.)	Years recorded to 1918.
(3) Northwest Montana.	Kootenai	Kalispell	2,965	20
	Blackfeet	Columbia Falls	3,100	22
	Cabinet	Fortine	2,975	12
	Lolo	Dayton	2,925	13
	Flathead	Plains	2,473	19
		Thompson Falls	2,424	6
		Libby	2,075	22
		Troy	1,880	16 to 1910
		Haugan and St. Regis	3,150	9
(4) Southwest Montana.	Bitterroot	Missoula	3,225	38
	Missoula	Hamilton	3,525	....
	Deerlodge	Como	3,750	10
		Ovando	4,050	20
		Hat Creek	....	....
		Phillipsburg	5,273	14
		Anaconda	5,330	18
		Butte	5,716	23
		Deerlodge	4,509	15
(5) North central Montana.	Helena	Babb	4,461	12
	Lewis and Clark	Helena	4,110	38
	Jefferson	Adel	5,200	19
		Wolf Creek	3,460	14
		Cascade	3,361	13
		Great Falls	3,350	26
		Fort Benton	2,630	33 to 1912
		Fort Shaw	3,500	23
		Augusta	4,071	18
		Choteau	3,810	19
(6) South central Montana.	Madison	Harlowton	4,160	23
	Gallatin	Bozeman	4,900	20
	Absaroka	Yellowstone	6,200	33
	Beaverhead	Redlodge	5,548	17 (18)
	Beartooth	Billings	3,115	21 (22)
		Busted	4,050	10
		Virginia City	5,880	29
		Hebgen Dam	6,700	12
		Norris	4,845	11
		Dillon	5,143	20
		Renova	4,360	19
		Bowen	6,080	11
		Three Forks	4,400	12 to 1915
		Big Timber	4,094	12
(7) Southeast Montana.	Sioux	Miles City	2,378	26
	Custer	Ekalaka	[1] 4,000	17
		Graham	[1] 4,000	10
		Crow Agency	3,401	38

[1] About.

It should be stated that most of the cooperative weather stations listed in Table 1 do not, as a rule, lie within the forests. Since they are the only ones available, they must nevertheless be used and the records will be of sufficient value for comparisons of the seven sections.

Within this territory we are fortunate in having several quite complete regular United States Weather Bureau stations which may be used as control stations for various sections. Of these Spokane, Wash., is used for north Idaho (Lewiston, Idaho, being too low and too far removed from the forests), Kalispell for western Montana, Helena for north central Montana, Yellowstone Park for south central Montana, and Miles City for southeast Montana. Records of sunshine, humidity, temperature, wind and precipitation are also available from Priest River Forest Experiment Station, within the timbered belt of northern Idaho.

In presenting the data on climate for use in this study, the year is begun October 1, for in this manner it is possible to review at a glance all of the factors which may or may not contribute toward a bad fire season.

FIRES AND CLIMATE BY THE SEVEN SECTIONS.

The data on forest fires, 1909 to 1919 by area, damage, cost, causes and classes are given in Tables 2 and 3 and are shown graphically in Figures 2, 3, 4, 5, and 6. The weather records for the same years are presented in Tables 4, 5, and 6.

TABLE 2.—*Fires according to the seven sections, 1909–1919, inclusive.*

Section.	Total national forest area.	Area burned per each 100,000 acres.	Average area per fire.	Estimated damage per fire.[1]
	Acres.	*Acres.*	*Acres.*	
North Idaho	3,476,380	22,728	234	$2,954
Central Idaho	4,375,925	45,750	1,154	4,256
Northwest Montana	6,986,718	19,332	281	1,940
Southwest Montana	3,488,059	6,121	130	471
North central Montana	2,922,525	8,003	410	1,433
South central Montana	4,979,930	924	97	497
Southeast Montana	710,619	1,077	48	277
Total	26,940,156			
Average		17,237	363	2,236

[1] The damage is the estimated value of timber and young forest destroyed.

TABLE 3.—*Numbers of fires in the seven sections, by classes and causes, 1909–1919, inclusive.*

Section.	Total number.	Number per 100,000 acres.								
		A.	B.	C.	Railroads.	Lightning.	Brush burning.	Campers.	Unclassified.	Total.
North Idaho	3,381	59.3	20.9	17.1	32.2	23.0	10.8	10.0	21.3	97.3
Central Idaho	1,735	19.4	9.9	10.4	.0	33.1	7.3	2.0	3.7	39.6
Northwest Montana	4,813	38.2	17.6	13.1	31.3	13.8	7.5	5.6	10.7	68.9
Southwest Montana	1,648	24.4	12.9	9.9	9.8	13.0	4.0	11.7	8.8	47.2
North central Montana	571	10.6	4.7	4.3	8.0	5.2	1.4	1.8	3.1	19.5
South central Montana	473	5.2	2.1	2.3	1.2	2.0	.7	2.7	2.9	9.5
Southeast Montana	160	7.0	8.0	7.5	.0	10.8	.1	3.7	7.9	22.5
Total	12,783									
Average	1,826	26.1	11.6	9.7	14.7	14.8	4.2	5.4	8.3	47.4

The data presented in Tables 2 and 3 show an average of close to 17,250 acres burned per each 100,000 for the entire district from 1909 to 1919. North and central Idaho and northwest Montana suffered most. These three sections have about 89 per cent of the total area which was burned; northwest Montana 19 per cent, north Idaho 17 per cent, and central Idaho 43 per cent. This great difference between the western and eastern sections appears to be due both to the relative number of fires and the areas per fire in each section. (See Table 3 and fig. 3.) Montana, east of the Continental Divide, shows an average number from 9.5 to 22.5 of fires per 100,000 acres, while the western parts show 39.6 to 97.3. The eastern sections show an average area per fire from 48 to 410 acres; north Montana and north Idaho 281 and 234, respectively; and central Idaho 1,154 acres per fire. In the last instance the high acreage is due chiefly to large fires in 1910 and 1919.

The damage per fire, given in Table 2, is based on estimates of merchantable-sized timber (stumpage) destroyed and of additional values of reproduction and young growth. If watershed values, grazing, and other phases were included, the figures would be much greater. They are mentioned here mainly for the purpose of bringing out the relations between the sections in this respect. Damage figures for southeast Montana are the lowest, as is also the average area per fire.

Fires which cover more than 10 acres are classed as C fires, and those which burn less than ¼ acre as A fires. Those between ¼ and 10 acres are B fires. Large fires are most numerous in the west and relatively few in the east, except in southeast Montana, where there are many surface fires.

In respect to the number of fires southwest Montana may be classed with the western sections, but from a standpoint of area per fire it resembles the eastern parts.

The outstanding causes of forest fires in this district are lightning, railroads, campers, and slash burning, of which lightning is the cause of the greatest number. By individual sections it appears that railroads are the most prolific source in north Idaho, northwest Montana, and north central Montana. Central Idaho and southeast Montana are free from railroads and railroad-caused fires. Central Idaho has comparatively few fires from any

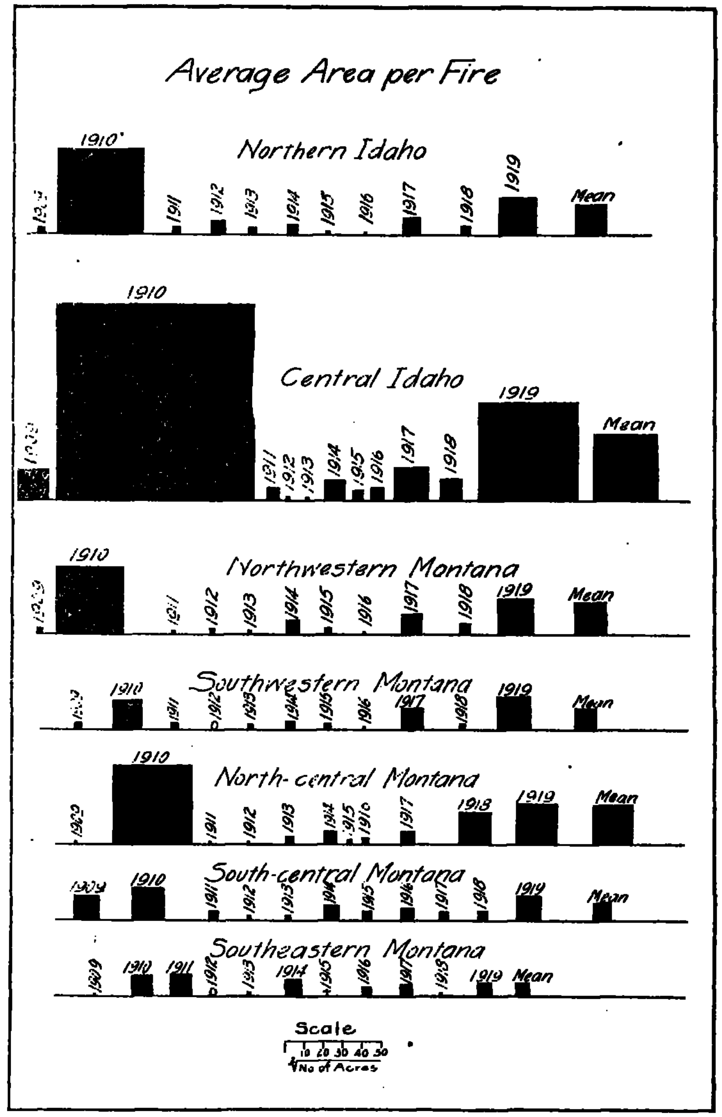

FIG. 2.—Average area per fire for the seven sections of Montana and north Idaho.

cause except lightning, which causes 84 per cent of all fires. Slash burning is the cause of many fires getting beyond control in north Idaho and northwest Montana. Many of the fires listed under this cause have, no doubt, been set in slash by parties who desire either to clear land or to comply with the State law compelling burning of slash.

The essential climatic elements, such as sunshine, air temperature, relative humidity, wind, and precipitation, including snowfall, are given in Tables 4, 5, and 6. In looking over these figures there does not appear to be any remarkable difference in the air movement, somewhat

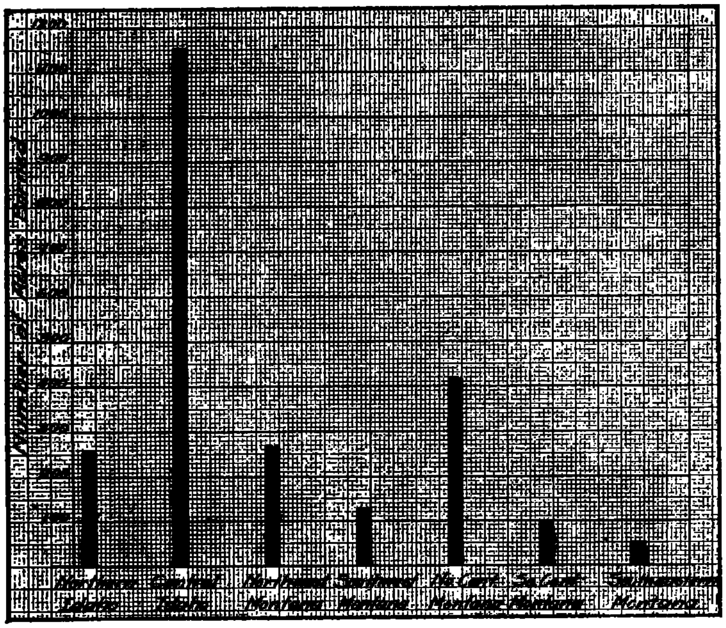

FIG 3.—Average area per fire by seasons for the seven sections of Montana and north Idaho.

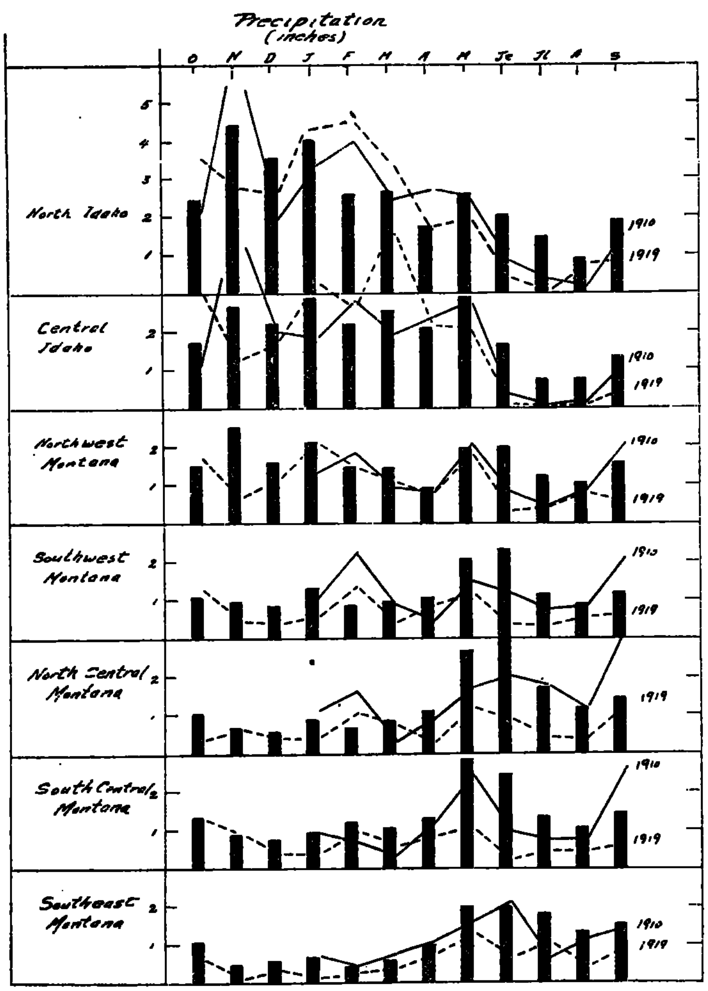

FIG. 4.—Average precipitation for each of the seven sections of Montana and north Idaho. (Based on published data of U. S. Weather Bureau for stations listed in Table 1.)

greater, to be sure, at Helena and Yellowstone Park. The average annual air temperatures do not differ so very much, but eastern Montana has a much colder winter and southeastern Montana a warmer summer than the western sections. Of the latter, central Idaho shows the warmer summer.

Precipitation, however, differs in a very striking manner; north Idaho has an annual average of 30.37 inches and eastern Montana only 14.22 inches. Central Idaho has only 1.40 inches for July and August, and eastern Montana nearly 3 inches. Central and western Montana sections are again intermediate. These differences are due to the fact that Idaho partakes of the Pacific coast type of precipitation and eastern Montana the continental type.

The greater amount of sunshine at Spokane in summer than at the other control stations, and the lower relative

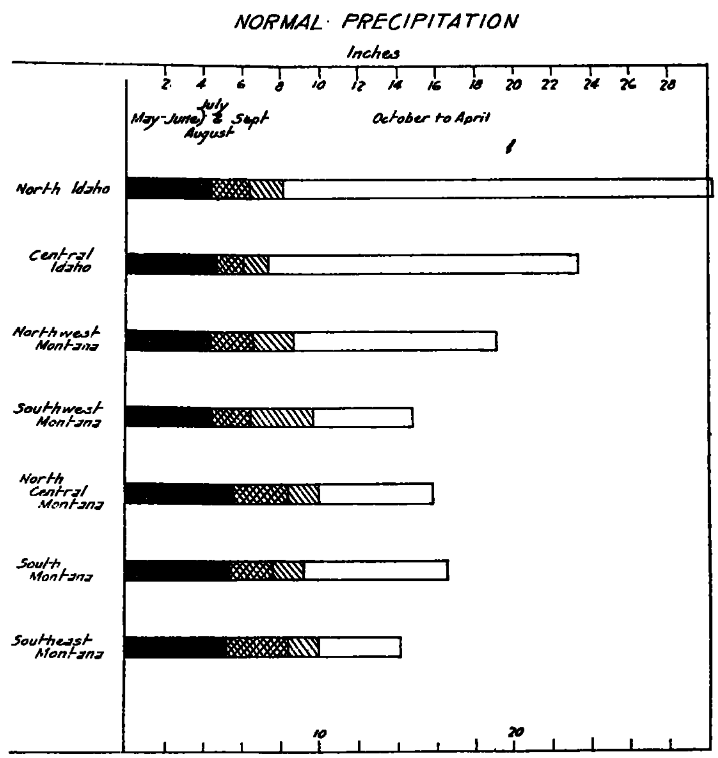

FIG. 5.—Precipitation by months for the seven climatic sections of Montana and north Idaho.

humidity reflect the dry summers west of the Bitterroot Range. The light snowfall in central and eastern Montana illustrates the lighter winter precipitation in these parts.

In Idaho this low rainfall in summer, which is accompanied by much sunny, warm weather and low humidity, produces a critical forest fire situation almost every year.

The reason for the greater devastation of forest by fire in Idaho would seem to be in the fact that, particularly in central Idaho, the summer rainfall and relative humidity are so much less than in the other sections. The heavier annual precipitation in Idaho, which is also usually abundant in spring, gives rise to a dense forest, often with a mass of undergrowth and much dead and down material, which by virtue of the low summer rainfall and low humidity become highly inflammable. The primary cause of this dry condition is found in the prevailing westerly winds, which lose moisture in passing the Cascades, become heated by compression in the descent on the eastern slopes, and create desert conditions over a stretch of 100 miles of flat land, where they are further heated without receiving any additional moisture. When these winds strike the forests, therefore, they exert a powerful drying influence.

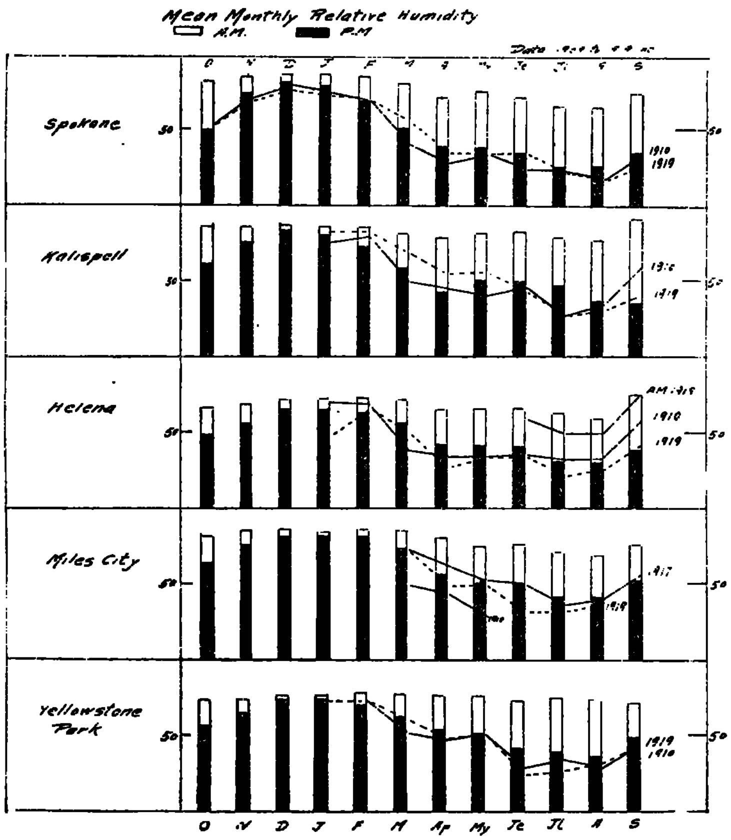

FIG. 6.—Relative humidity by months for the seven sections of Montana and north Idaho.

TABLE 4.—*Average precipitation.*

[Data from stations listed Table 1, U. S. Weather Bureau.]

	October.	November.	December.	January.	February.	March.	April.	May.	June.	July	August.	September.	Year.
North Idaho	2.43	4.43	3.55	3.90	2.60	2.65	1.78	2.60	2.07	1.50	0.92	1.94	30.37
Central Idaho	1.82	2.55	2.10	2.56	2.10	1.97	1.95	2.24	1.56	.70	.70	1.26	21.F1
Northwest Montana	1.48	2.50	1.60	2.10	1.47	1.46	.90	1.93	2.00	1.25	1.07	1.54	19.30
Southwest Montana	1.07	.97	.82	1.30	.86	.96	1.05	2.08	2.32	1.15	.90	1.28	14.76
North central Montana	1.05	.68	.59	.86	.65	.86	1.09	2.67	3.00	1.72	1.20	1.48	15.85
South central Montana	1.30	.86	.75	.91	1.20	1.04	1.30	2.85	2.46	1.37	1.06	1.45	16.55
Southeastern Montana	.98	.47	.52	.61	.50	.72	1.11	2.41	2.63	1.50	1.30	1.47	14.22

AVERAGE AIR TEMPERATURE (F.°).

North Idaho	45.5	35.4	28.4	26.0	28.5	36.7	45.0	51.3	56.0	65.5	63.8	54.5	44.7
Central Idaho	48.6	39.3	30.9	27.9	31.6	40.6	48.2	53.8	61.9	67.8	66.0	56.4	47.7
Northwestern Montana	44.5	34.3	26.0	22.5	26.4	35.2	45.0	53.0	58.4	64.3	63.0	52.5	42.8
Southwestern Montana	43.5	33.5	24.6	22.0	23.2	33.0	42.5	49.0	57.0	63.5	62.0	53.2	42.2
North central Montana	44.6	30.5	24.3	20.5	22.6	25.8	41.5	50.8	58.8	64.8	64.0	55.2	41.8
South central Montana	44.5	32.0	24.5	19.8	22.5	30.5	41.2	50.3	59.3	65.9	63.2	55.0	42.4
Southeastern Montana	46.1	31.5	21.9	16.5	18.9	30.1	43.5	54.1	63.7	70.4	68.9	59.5	44.7

TABLE 5.—*Humidity, sunshine and wind.*

Control station.	Relative humidity (per cent).					Sunshine per cent of possible.			Wind movement (miles per hour).	
	Average for summer.[1]		Lowest monthly in summer.		Average, August, P. m.	Summer.[1]	Average, August.	Maximum monthly.	Summer.[1]	Average, August.
	P. m.	A. m.	P. m.	A. m.						
Spokane	32.5	70	16	51	25	65	74	89	6.2	5.3
Kalispell	44.7	82	27	......	36	60.5	69	87	4.8	4.4
Helena	37.6	63	22	40	30	65	73	88	7.1	7.8
Yellowstone Park	44.7	75	26	63	36	62.6	72.6	....	7.4	6.9
Miles City	49.0	75	28	......	42	......	......	....	6.0	5.1

[1] April to September, inclusive.

TABLE 6.—*Average snowfall for sections of Montana and north Idaho.*

[Data 1909–1919, inclusive, in inches.]

Section.	October.	November.	December.	January.	February.	March.	April.	May.	Total.
North Idaho	0.5	9.1	19.4	21.3	19.8	10.8	1.2	0.2	82.3
Central Idaho	1.0	5.2	11.5	18.9	16.7	8.5	2.0	.9	64.7
Northwest Montana	.8	7.9	15.4	19.7	15.5	8.5	1.2	.4	79.4
Southwest Montana	4.7	7.0	9.1	15.2	13.8	7.7	3.9	2.6	64.0
North central Montana	8.0	4.8	5.9	10.3	9.0	7.4	5.3	3.0	53.7
South central Montana	5.8	6.8	7.9	12.0	9.6	8.8	6.1	5.9	62.9
Southeastern Montana	1.8	4.6	6.9	10.3	4.8	6.6	3.4	2.3	39.7

That the eastern sections of the district, particularly the areas east of the Continental Divide, are less exposed to this dry atmospheric condition is shown by the fact that the average relative humidity for August at Kalispell is 36 per cent, at Helena 30 per cent, at Miles City 42 per cent, and at Yellowstone Park 36 per cent.

As to secondary causes contributing toward more forest fires in Idaho than elsewhere in the district it may be mentioned that the wind always strikes the sunny slopes and blows hardest at the time of the day when the air temperature and moisture deficit are greatest. Over the Clearwater region in central Idaho the wind blows parallel with the ridges in summer whereby its drying, carrying and fanning effect is increased. In northern Idaho, and over the greater parts of Montana, on the other hand, the trend of topography is transverse to the prevailing wind, so that each pronounced ridge checks the wind and presents natural breaks which retard the spread of large forest fires.

Since the moisture content of both dead[1] and living[2] leaves is lowered by a decrease in the relative humidity of the air, and since all woody tissue becomes drier under its influence, it is easy to understand how these climatic and topographic relations produce the critical conditions which result in the bad forest fires in Idaho.

[1] By the investigations of S. B. Show, Climate and Forest Fires in California, Journal of Forestry, December 1919, p. 915, and by the Priest River Experiment Station it has been found that the dead material on the forest floor receives and gives up moisture according to the relative amount of moisture in the atmosphere.

[2] "In the case of specialized water tissue, the water which forms in the bulk of the cell represents a store which is drawn upon by other living tissue and in particular by the photosynthetic cells, in time of drought."—(*Plant Anatomy*, by Haberlandt.)

FIRES AND CLIMATE ACCORDING TO YEARS.

The data on fires by years are given in Table 7 and the weather conditions (for north Idaho and north-central Montana) appear in Tables 9 and 10.

A compilation of fires which are caused by lightning is given in Table 8. These data may be taken as fair indications of the hazard from this cause. It is of interest to note that 56 per cent of the total number is confined to the two Idaho sections. Lightning activity is greatest in Idaho, intermediate in western Montana and relatively small in the central Montana sections but somewhat increased again in southeastern Montana.

The fire records for the entire district for the last 11 years show six years comparatively free from bad forest fires. These are 1911, 1912, 1913, 1915, and 1916. These years show one and sometimes two of the summer months with deficient rainfall, but the summer averages were above normal. The beginning of 1915 occasioned considerable anxiety by an unusually early and warm spring, but the late spring and summer rains were abundant.

In marked contrast to these favorable seasons are the five years of bad forest fires, 1910, 1914, 1917, 1918, and 1919.

The year 1910 will always be remembered as one of the very worst fire years in the Pacific Northwest. More timber land was burned over in that year than during all of the 10 years following. The damage was particularly heavy in northern Idaho.

In going over the weather records for this year it is seen that the snowfall and the winter precipitation were about average. Even the month of May showed a fair amount of rain, but from the beginning of June until the latter part of August the drought was intense. During this summer Spokane and all the other Weather Bureau control stations in the district showed air temperature, wind movement, and moisture deficit greater than normal. The fire season came to a close with snow about August 19.

TABLE 7.—*Fires according to years.*

Year.	Total area burned (acres).	Average areas per fire.	Number of acres burned per each 100,000 acres.						
			North Idaho.	Central Idaho.	Northwest Montana.	Southwest Montana.	North central Montana.	South central Montana.	Southeast Montana.
1909	22,392	19	400	85	29	19	0	42	0
1910	2,725,796	1,724	17,246	22,627	12,731	1,646	5,755	368	390
1911	6,920	18	64	45	3	23	1	10	158
1912	2,974	11	59	1	11	0	1	11	0
1913	3,090	6	34	4	8	22	10	12	8
1914	114,433	55	321	993	624	145	171	111	100
1915	14,480	13	49	186	50	22	2	7	0
1916	9,134	15	7	159	2	7	9	18	62
1917	171,907	106	726	766	1,096	874	116	19	248
1918	58,067	49	260	649	217	25	137	12	1
1919	1,514,555	671	3,562	20,235	4,562	3,338	1,799	335	109
Total	4,643,748	......	22,728	45,750	19,332	6,121	8,003	924	1,077
Average.	422,159	363	2,066	4,159	1,757	556	728	84	98

TABLE 8.—*Lightning fires, number per each 100,000 acres.*

Year.	North Idaho.	Central Idaho.	Northwest Montana.	Southwest Montana.	North central Montana.	South central Montana.	Southeast Montana.	Average.
1909	0.9	0.2	0.4	0.3	0	0.1	0.3	0.3
1910	.8	1.6	.8	.6	.5	.3	2.7	.8
1911	.3	1.0	.3	.4	.1	.2	.6	.4
1912	.3	.3	.3	.1	.2	.1	0	.2
1913	.4	.9	.3	.2	.1	0	1.1	.3
1914	3.1	8.7	1.8	1.9	.5	.3	.7	2.7
1915	7.8	6.2	1.8	1.1	.1	.1	.1	2.7
1916	.9	3.2	1.0	1.6	.2	0	1.4	1.2
1917	.7	1.2	.8	1.0	.8	.3	2.2	.8
1918	4.5	4.0	2.3	1.7	.4	.2	.4	2.1
1919	3.3	5.9	4.0	4.0	2.2	.5	1.3	3.3
Total	23.0	33.1	13.8	13.0	5.2	2.0	10.8	14.8

TABLE 9.—*Weather conditions by years for north Idaho and control station, Spokane, Wash.*

Year.	Precipitation (inches).									Air temperature, °F.				Sunshine (per cent possible).				Air movement (miles per hour).				Relative humidity (per cent).			
	Snowfall.	October-December, inclusive.	January-March, inclusive.	April.	May.	June.	July.	August.	September.	May.	June.	July.	August.	May.	June.	July.	August.	May.	June.	July.	August.	May.	June.	July.	August.
1910	102	11.68	10.14	2.72	2.55	0.81	0.26	0.18	1.56	54.5	57.5	65.8	60.2	73	75	88	74	7.0	7.4	6.4	5.7	31	29	19	22
1912	89	7.02	6.89	1.96	2.92	2.10	1.70	2.38	1.46	53.2	62.0	62.0	60.0	64	68	66	60	6.4	6.0	5.6	5.9	40	34	34	39
1914	70	7.39	9.52	1.22	1.77	2.20	1.24	.32	2.48	54.5	57.5	67.0	64.5	62	53	82	79	6.1	6.9	5.8	5.7	34	33	22	19
1916	143	10.60	13.20	1.91	2.37	3.23	2.08	1.24	2.33	46.8	55.6	61.2	62.0	43	58	73	81	8.1	6.1	7.1	5.0	41	38	30	25
1917	137	8.05	8.77	2.98	2.05	1.30	.04	.08	.83	51.3	56.6	66.0	64.6	51	75	86	90	6.2	7.8	6.8	5.3	40	31	18	17
1918	80	12.55	11.15	.75	.16	.70	1.25	.25	.12	49.5	63.5	67.0	61.2	[1] 55	78	74	70	8.4	6.2	5.6	6.0	33	22	25	34
1919	69	8.95	12.36	1.97	1.98	.42	.08	.78	.88	52.7	59.3	67.2	65.2	[2] 72	88	89	81	8.3	6.6	5.9	5.6	35	33	21	16
Average for complete record [3]	82	10.41	9.12	1.78	2.60	2.07	1.50	.92	1.94	51.9	58.8	64.6	63.2	58	68	77	[1] 76	6.8	6.9	5.9	5.2	38.2	33.2	25.3	25

[1] 73 in April. [2] 78 in April. [3] 1880–1910.

TABLE 10.—*Weather conditions by years and months for north central Montana and for the Helena, the control, station.*

Year.	Precipitation (inches).									Air temperature, °F.				Sunshine (per cent possible).				Wind movement (miles per hour).				Relative humidity (per cent).			
	Snowfall.	October-December, inclusive.	January-March, inclusive.	April.	May.	June.	July.	August.	September.	May.	June.	July.	August.	May.	June.	July.	August.	May.	June.	July.	August.	May.	June.	July.	August.
1910	45	......	2.74	0.89	1.73	2.01	1.80	1.17	3.33	53.7	60.8	67.3	61.1	57	57	72	80	7.7	6.9	6.8	6.3	34	36	32	32
1912	50	3.31	1.98	1.02	3.75	.88	2.00	2.28	2.35	51.3	60.6	60.9	61.0	57	55	77	62	9.4	8.6	8.0	8.2	52	43	46	42
1914	55	3.88	1.59	1.36	2.79	5.17	.41	.33	.75	52.7	57.7	69.0	63.5	56	57	71	69	8.3	8.8	8.3	8.5	45	49	33	30
1916	52	2.32	3.07	1.39	4.10	5.55	2.15	1.32	1.87	47.0	56.5	65.5	63.0	44	60	68	81	9.9	9.2	8.6	8.1	48	47	38	47
1917	85	3.87	3.22	1.70	3.74	1.62	.35	1.18	2.27	48.8	56.6	68.3	64.0	55	75	88	78	8.2	9.1	8.7	7.9	50	37	24	32
1918	51	3.10	2.25	1.38	1.36	1.07	2.25	1.50	1.87	48.3	64.4	64.7	62.4	53	77	64	66	9.2	8.2	7.2	8.5	36	31	38	36
1919	34	1.35	2.09	.21	1.24	.89	.43	.38	1.30	53.7	62.4	68.8	66.9	[1] 61	61	71	80	9.2	8.3	8.7	8.1	[2] 34	34	33	22
Average for complete record	54	2.32	2.59	1.09	2.61	3.00	1.72	1.20	1.48	50.7	59.6	65.1	63.3	[3] 60	[3] 65	[3] 73	73	[4] 6.8	[4] 7.2	[4] 7.7	7.8	42	41	31	30

[1] 62 in April. [2] April 28 per cent. [3] Years 1909–1919. [4] 19 years, 1916.

The season of 1914 was preceded by a normal fall, winter, and spring precipitation, but there was a marked deficiency of snowfall and an early melting. The May and June rainfall was about average, but somewhat low in May and high in June. The drop in July was most pronounced in the northwestern and the central Montana sections; the August rainfall was considerably below normal everywhere, almost nothing in central Idaho. The summer temperature, 1914, summer sunshine, wind movement, and moisture deficit were in most cases greater than normal. The result of these conditions are seen in the large number of fires in July and August, and the comparatively large area per fire. As in 1918 the season was most severe in Idaho, and lightning fires were numerous and difficult to control. In central Idaho occurred the largest number of lightning fires on record for any one year.

The winter of 1916–17 was notable for its great quantities of snow and precipitation well above normal until the month of May. From that time on the rainfall was much below the average and reached unusually low points in July and August. On account of the abundant snowfall and late melting everyone predicted a favorable season, but the sudden and unusual drought which followed precipitated a bad fire season. As in case of all of the bad fire years the sunshine, wind movement, summer temperature, and moisture deficit were greater than normal. The most noticeable feature of the 1917 fires was the low percentage caused by lightning. On this account central Idaho showed no greater area burned than north Idaho. The year 1918, which is the least severe of the five bad fire years, began with a heavy snowfall in the early part of the winter, followed by abundant January and February rain, which caused floods and early melting of the snow, particularly in the Idaho sections. This was followed by an unusually dry spring; so dry that the height growth of young trees was noticeably below the average. The season would, no doubt, have been very bad had it not been for the abundant rains in the middle of July. In all except the central Montana sections the May and June temperature, sunshine, wind movement, and moisture deficit were greater than normal. The fire season, based on number and area of fires, was much more severe in the Idaho than in the Montana sections and began exceptionally early. The number of lightning fires was in most sections well above the average.

The year 1919 had an unusually large number of fires in all parts of the district. It had the dryest spring and summer on record since 1883 on the Pacific slope and the dryest on record for the eastern slope (observation begun 1880, see fig. 12 and Table XII). The deficit in total annual precipitation from October 1, 1918, to September 30, 1919, is as follows: North Idaho 5 per cent, northwest Montana 27 per cent, southwest Montana 42 per cent, north central Montana 46 per cent, and in southeast Montana 51 per cent, with corresponding deductions elsewhere. The deficit for May, June, July, and August combined in each section are, in the order usually given: 42 per cent, 50 per cent, 50 per cent, 63 per cent, 66 per cent, 72 per cent, 54 per cent. Central Montana shows the greatest summer deficit. The more outstanding facts for the whole district for 1919 are: A very light snowfall everywhere; frozen ground in the fall; much melting of snow in late December, 1918; most of winter precipitation in the form of rain; comparatively little spring rain, followed by an unusually dry and a very warm summer; it was, moreover, the third consecutive dry season. Sunshine, wind movement, and mositure deficit were much above the average for all sections. It should be noted that the average afternoon July and August relative humidity for Spokane was only 18.5 per cent as compared with a normal of 25.2 per cent. The deficit at Helena for the same period was 9 per cent; for Yellowstone Park, 18 per cent; and for Miles City, 8.5 per cent. The average sunshine at Spokane for July and August, 1919, was 80 per cent and 85 per cent, compared with averages of 62.5 per cent and 70.5 per cent. It was also well above the average at

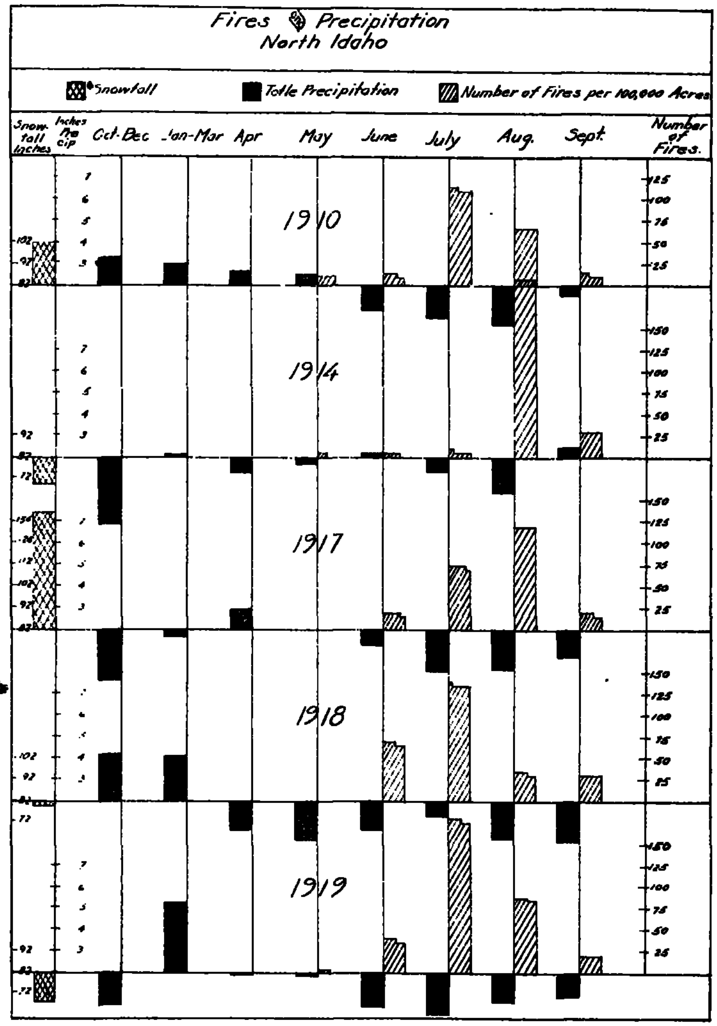

FIG. 7.—Deficit in rainfall and forest fires for north Idaho, 1910, 1914, 1917, 1918, and 1919.

the other control stations. Air movement at Spokane, Kalispell, and Yellowstone Park were considerably above normal and greater than in any previous fire year.

The light snowfall, lack of spring rain, and spring temperatures above normal were the causes of the unusually early start of the fires in 1919. The May fires in nearly every group exceeded both the 11-year average and those of any other single year. Fires in June were numerous in all parts of the district, and, while they did not burn with the same fierceness that the fires did later in the season, considerable difficulty was experienced in controlling them, principally, because of the fact that the protective force was just being put on.

FIRES AND WEATHER BY MONTHS.

A comparison of fires and weather by individual months brings out many points worth noting; but since the presentation of the data in tabular form leads to such a great mass of detail a diagrammatic presentation is given. This requires less space and can be more readily visualized.

The correlation which is given in figures 7 and 8 was carried out for all of the seven groups in the district. Only two of these are given here and one which shows the average relations for 1910, 1914, 1917, 1918, and 1919 for four sections.

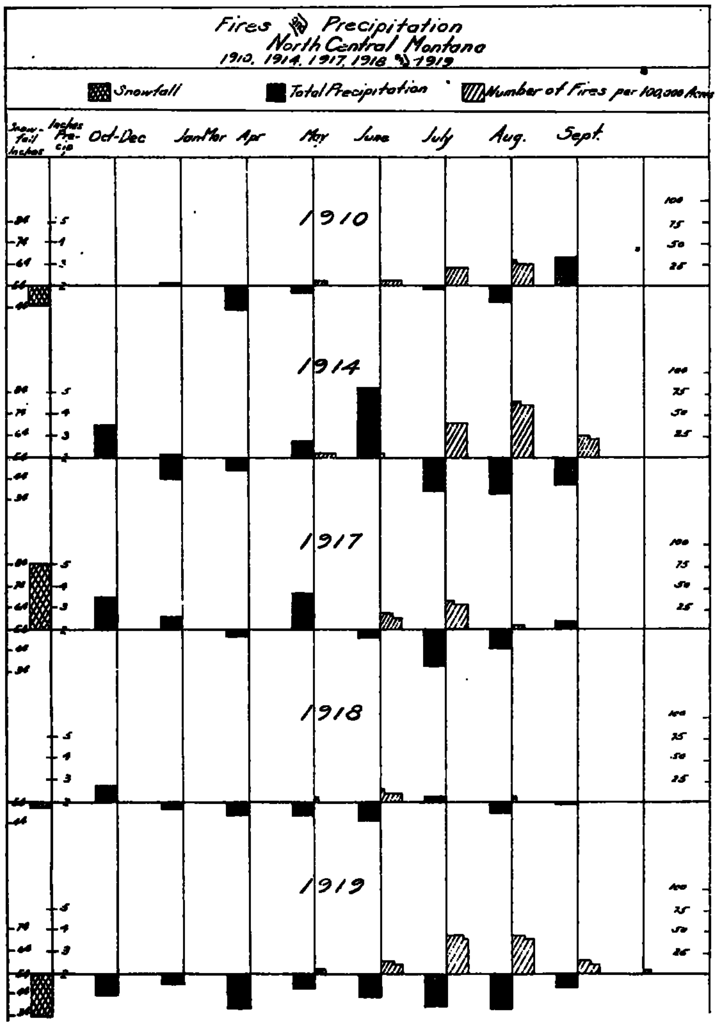

FIG. 8.—Comparison of precipitation and forest fires for north-central Montana, 1910, 1914, 1917, 1918, and 1919.

In these diagrams the difference between 2 inches of rainfall and the actual amount which fell has been used, mainly because the rainfall data for the safe years 1911, 1912, 1913, 1915, and 1916 show that 2 inches per month comes close to the safety limit in July and August.

It is recognized, however, that it is difficult to establish these relations definitely, mainly, because the origin of the fires, and especially lightning fires, vary widely from year to year. However, by averaging the number of fires and the precipitation for each month these relations may be approximated as closely as it is possible from the present data.

Referring to the diagrams it is seen that the safety line of precipitation in northern Idaho and north central Montana is about 2 inches per month from June through September. This is shown very clearly for May, June, and July in northern Idaho, 1914, and for the entire summer 1918 for north central Montana.

It is seen further that the quantity of winter snowfall or total precipitation bears little relation to fires during the following summer. The great quantity of snow during winter of 1917 and a precipitation about normal until May did not stave off a very bad season, which began as soon as the rainfall fell below 2 inches.

It may be well to fix our attention to the months of May and June for a little closer consideration. June does not show a critical fire situation, provided May has

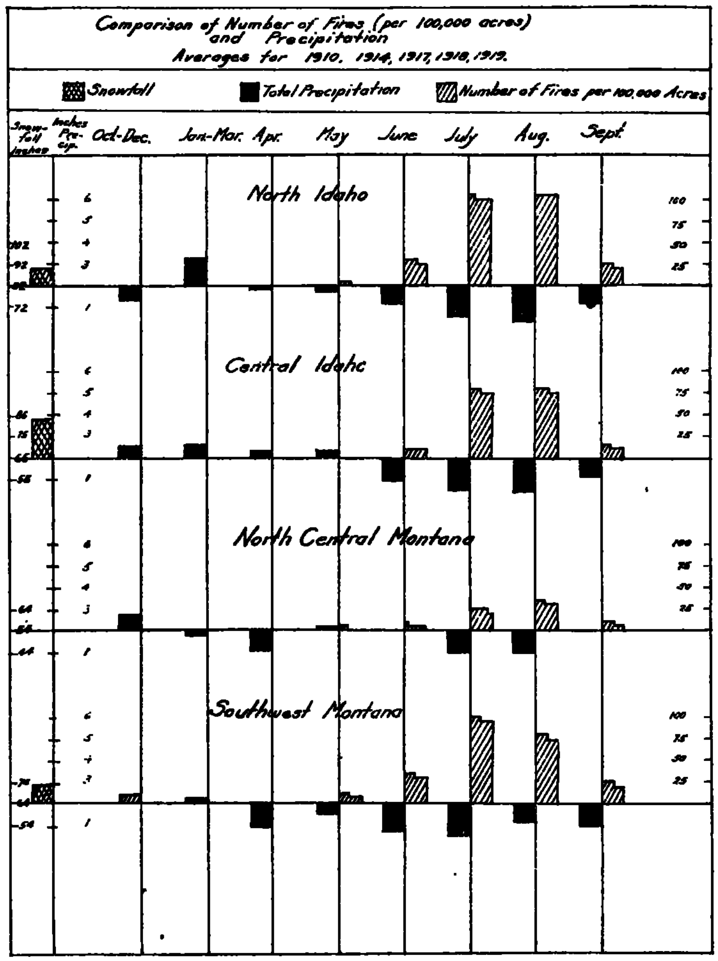

FIG. 9.—Relation of rainfall deficit to forest fires for the years 1910, 1914, 1917, 1918, and 1919, in north Idaho, central Idaho, north-central and southwest Montana.

about 2 inches of rainfall. The year 1919 shows somewhat of an exception, and the explanation lies most likely in the fact that June, 1919 had 88 per cent sunshine compared with an average of 68 per cent and because neither the spring rains nor the water from the melted snow soaked into the frozen ground. If, on the other hand, May shows a considerable deficit, and this continues throughout June, there will be many fires in June. If, as in the case of 1918, both the April and May rainfall is considerably below 2 inches, a dry June will bring on many fires.

In Figure 9 are shown the relations between the deficit in precipitation and the number of fires per month. According to averages for 1910, 1914, 1917, 1918, and 1919, the relations are quite regular. From the data it is possible to derive a figure which, when multiplied by the difference expressed by (2 − actual rainfall for the month), approximates the number of fires for that month. For north Idaho this multiplier is 10 for May, 30 for June, 100 for July and August, and 30 for September: e. g., in north Idaho the June deficit (Fig. 9) is 1.60 inches. This multiplied by 30 equals 48. The average number of fires for that month is 53. The factor 10, 30, 100, etc., is obtained from the actual records of the number of fires by formula

$$2 - \text{actual precipitation} = \frac{\text{number of fires}}{x}.$$

experiment station and covered 1,200 acres in one afternoon. On August 19, very serious forest fires occurred on most of the north Idaho forests.

It is of interest to note that the records for Spokane, Wash., also show unusually high temperature and low humidity and somewhat increased pressure at these times, but the wind there and at the Forest Service lookout stations show no very unusual movement.

The periods of high pressure and clear sunny weather, when the daily air temperatures approach 100° F. and when the relative humidity is very low in the afternoon, present very critical weather for forest fires.

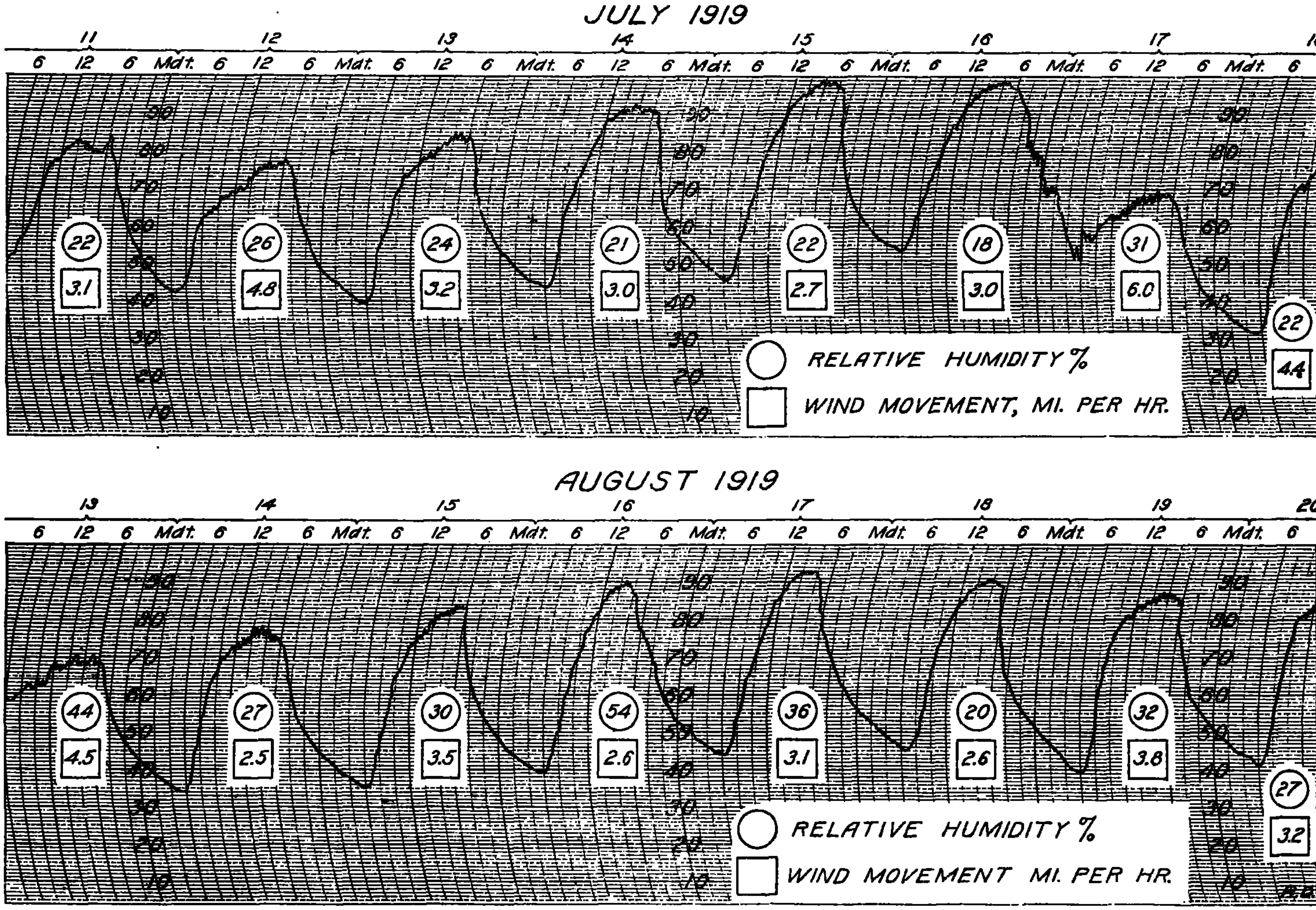

FIG. 10.—Daily rise in air temperature and lowering of relative humidity culminating in critical weather for forest fires, Priest River Forest Experiment Station, 1919.

ESPECIALLY DANGEROUS WEATHER FOR FOREST FIRES.[3]

The geographic and topographic relations which have been discussed above, and the prevalence of high-pressure areas bring about clear, warm, dry weather in summer in northern Idaho during July and August. At certain periods during these months, the weather conditions frequently approach a climax of high air temperature and low relative humidity. Examples of this are available from weather records at the Priest River Forest Experiment Station and fire records, July 11 to 19, 1919, and from August 13 to 20, 1919. The temperature curves in Figure 10 show this very clearly. On July 18, a serious fire broke out in a slashing five miles away from the

[3] Mr. Edw. A. Beals has given a very interesting discussion on weather conditions attending three great forest fires, Baudette, Columbia, 1902, and Idaho, 1910, in the February Mo. WEATHER REV. Feb., 1914, 43: 111-119.

LENGTH AND INTENSITY OF THE FIRE SEASON.

The numbers of fires in each section of the district have been averaged by months to show relatively the time of beginning and ending of forest fires, the month of greatest intensity, and the relations of air temperature and precipitation to the fires. (See Table II and Fig. 11.)

North central Montana appears to have the longest fire season. It begins in April and ends in October. April fires occur also in the two western Montana groups. In central Montana these early fires occur chiefly in the dry grass or the slash left over from the preceding fall or winter. There is no appreciable difference between the groups in air temperature. Figure 11, however, shows that the April rainfall and the annual snowfall in these parts is lower than elsewhere.

Other significant points brought out by this comparison is that the period of low summer rainfall usually corresponds closely with that of the highest air temperatures, that a rainfall of less than 2 inches per month after March or April brings up the fire curve in every section, and that there is an almost direct relation between the number of fires curve and the rainfall deficit under 2 inches per month.

For a closer comparison of the different climatic factors and forest fires the climatic data for the Priest River Experiment Station and the fire data for Kaniksu National Forest, within which the station is located, have been shown in Figure 12. This also reveals the rapid rise of the fire curve as soon as the rainfall drops below 2 inches per month. Other interesting relations are the close correlation of precipitation and soil moisture and the time of maximum forest fires at a time when these two factors and the relative humidity are lowest.

TABLE 11.—*Average number of fires by month per 100,000 acres.*

[Record 1909–1919, inclusive.]

	April.	May.	June.	July.	August.	September	October.
North Idaho	0.00	0.01	0.12	0.46	0.59	0.15	0.01
Central Idaho	.00	.0+	.03	.36	.39	.09	.00
Northwest Montana	.0+	.02	.10	.59	.51	.08	.01
Southwest Montana	.01	.03	.13	.43	.50	.16	.01
North central Montana	.01	.02	.04	.14	.21	.10	.02
South central Montana	.00	.0+	.01	.05	.06	.03	.0+
Southeast Montana	.00	.05	.11	.35	.49	.08	03

PRECIPITATION RECORDS 1880 TO 1919.

The most noticeable thing about the climatic records for the last 10 years is the unusually low summer precipitation for the three consecutive years, 1917, 1918, and 1919. In order to learn whether this was an unusual occurrence or a thing to be expected periodically the writers examined precipitation records for the last 40 years from stations east and west of the Continental Divide. These data are presented in Table 12[4] and figure 13.

The data for the 40-year rainfall west of the Continental Divide (Table 12) show a very low precipitation 1917, 1918, and 1919. The May and June rainfall was also quite scanty during the last two years and the July–August rain for 1917 and 1919 below normal. When we consider that the summer rainfall 1918 did not come until after the middle of July and that the May and June rain of that year was the lowest on record, there is no wonder that 1918 was a bad year for forest fires.

During 1888 and 1889 the July and August rain was also very low, but the records show at that time considerable May and June rain. The year 1889 is remembered as one of the very worst fire seasons in the Pacific Northwest.

Records for 1910 do not indicate such very critical conditions as the fire records would have us believe. During that year there was almost no June and July rain, and the fire season, though very intense, was limited to the first three weeks in August, during a period of high wind and air temperature.

East of the Continental Divide the annual precipitation for 1919 was the lowest since 1889 and the combined May–June and July–August rainfall the lowest on record.

[4] The averages for the Pacific slope are made from the records of Spokane, Missoula, and Walla Walla and for the eastern slope from Helena, Havre, and Miles City.

TABLE 12.—*Precipitation on the Pacific slope and eastern slope, 1880 to 1920.*

Year.	Pacific slope.[4] (Averages.)			Eastern slope.[4] (Averages.)		
	Annual.	May–June.	July–August.	Annual.	May–June.	July–August.
1880	[1] [17.71]	4.53	2.90	13.41	5.13	3.87
1881	22.50	3.91	2.85	15.64	5.46	4.88
1882	20.03	4.75	3.12	11.07	4.71	3.42
1883	13.47	3.21	[[1] 0.18]	12.08	3.70	2.69
1884	20.59	4.62	[[1] 2.90]	18.33	5.99	4.94
1885	17.16	5.78	1.03	9.87	6.02	2.52
1886	15.81	2.95	1.29	12.42	5.60	2.09
1887	17.97	5.37	2.81	14.94	7.88	3.99
1888	15.64	4.53	0.32	12.37	6.04	2.66
1889	12.65	4.32	0.59	8.80	3.07	2.57
1890	13.92	4.33	1.45	10.03	4.25	2.43
1891	18.41	5.31	2.84	16.65	8.29	4.55
1892	15.68	5.16	1.44	13.05	6.53	2.90
1893	22.48	6.59	2.38	14.32	5.83	3.93
1894	17.76	3.98	2.13	13.84	6.36	2.03
1895	12.68	3.00	2.48	11.46	4.80	2.85
1896	17.75	4.62	2.46	14.53	6.20	3.17
1897	21.83	5.30	4.00	13.49	5.59	1.90
1898	14.79	5.47	1.78	13.99	6.23	3.01
1899	19.79	3.63	3.57	14.97	6.27	3.54
1900	17.66	6.02	3.04	11.20	3.43	4.86
1901	15.15	4.42	2.10	14.55	7.11	4.42
1902	18.19	4.99	2.95	11.21	6.38	2.50
1903	15.49	3.47	3.69	12.46	4.27	5.86
1904	13.62	3.09	0.99	8.45	3.81	1.57
1905	15.90	6.43	1.91	9.75	4.79	3.58
1906	17.67	5.46	1.42	15.00	7.60	3.08
1907	16.27	4.02	3.35	13.59	7.21	3.04
1908	14.04	4.77	3.33	16.90	8.76	3.51
1909	17.10	3.50	3.54	15.35	6.81	4.64
1910	15.16	3.05	2.34	11.61	4.02	3.09
1911	12.41	4.29	1.86	16.39	5.29	5.94
1912	18.54	5.49	4.49	15.68	6.67	4.93
1913	17.06	4.89	2.12	13.78	5.53	3.73
1914	13.58	4.28	1.96	14.29	5.83	3.51
1915	17.20	6.82	3.01	17.60	6.92	7.13
1916	17.80	5.67	2.00	18.50	7.13	5.90
1917	14.54	4.35	0.77	13.71	4.84	2.86
1918	12.63	1.50	2.99	11.31	2.92	4.75
1919	14.20	2.07	1.40	9.18	2.60	1.78
Mean	16.63	4.50	2.29	13.50	5.64	3.61

The total annual precipitation, which appears to have reached the lowest points at periods of 15-year intervals, has no influence upon the fire season unless associated with summer drought. The three-year seesaw shows a low downpour every third season, the only exception being an interval of three wet years, 1905, 1906, and 1907. This three-year fluctuation is in accord with those found at Greenwich, England, by Dr. H. H. Hildebrandsson.[5] In the eastern and the southern parts of the United States[6] this fluctuation appears also, but is less regular than in Europe and the Western States. The fluctuations are very likely induced by the oceanic-pressure areas, on which much has been written. The relations of these pressure areas over the Pacific to the climate of Northwest America has not been worked out.

CHANCES OF PREDICTING DANGEROUS WEATHER CONDITIONS.

It should be remembered that since the atmospheric pressure areas require but one day to travel from the Pacific coast to the Rocky Mountains, and since there are no permanent weather stations to the west of the Pacific coast, it is evident that the basis for forecasting weather in the Northwestern States is largely wanting.

The data presented should have their value in deciding upon distribution of men and funds for fire protection.

[5] Cycles of Sun and Weather: *Nature*, April, 1912, p. 147.

[6] Secular Variations of Precipitation in the United States, by Alfred J. Henry, *Bulletin American Geographical Society*, Vol. XLVI, March, 1914. See also the articles by C. F. Brooks, Heryk Arctowsky, F. Nansen, H. Hildebrandsson, H. F. Blanford, E. Huntinton, and A. Schuster, on Pressure, Sunspots, and Climatic Controls.

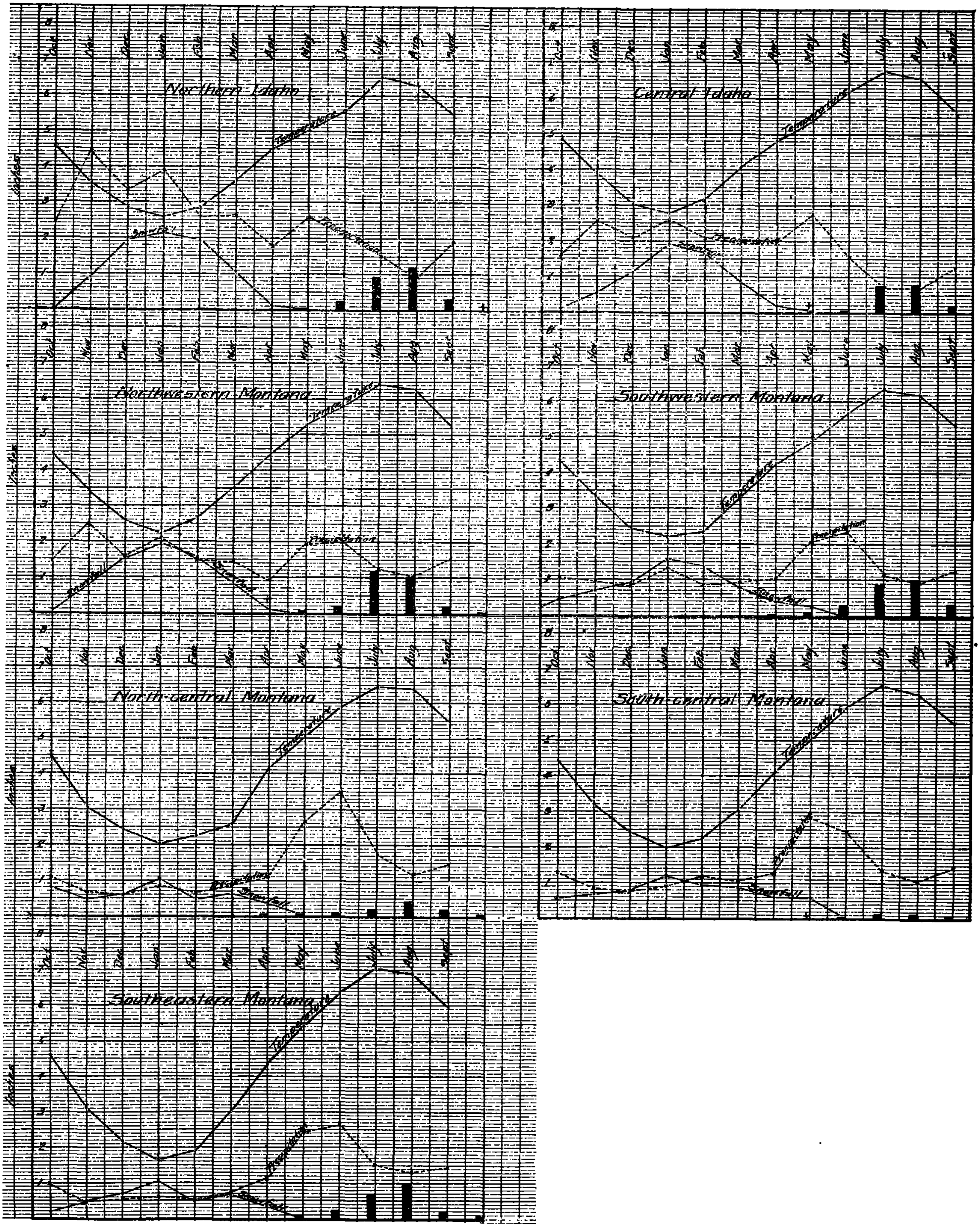

FIG. 11.—Relation between forest fires, precipitation, and air temperature for the seven climatic sections of Montana and north Idaho.

The averages of precipitation and temperature may be used as a basis by which to compare current weather conditions from month to month for the different groups of District 1. In this way an estimate may be gained of the intensity of the drought which is to follow in the summer.

One difficulty of applying these data in fire protection lies in the fact that our records do not extend back over a sufficiently long period, and that summer rainfall bears a closer relation to fires than does the annual precipitation. We may say with Robert DeC. Ward (*Scientific Monthly*, September, 1919) that actual rainfall records in this country are too short to give any definite indication of secular variations. The longest records cover 100 years, and a few stations have records of more than 50 years in length. While a study of these records shows a more or less definite and recognizable long-period fluctuation, they appear to be largely localized, and no definite conclusions can be drawn for extended areas.

There are several ways *of keeping informed regarding* the weather conditions. From records of evaporation at the Priest River Forest Experiment Station for several years it appeared that if the evaporation from a free water surface is more than five times the amount of precipitation, dangerous conditions will soon follow, or if an average of more than 25 cubic centimeters of evaporation per day takes place from the Livingston porous-cup atmometer a dangerous condition will soon result.

The relation between evaporation and precipitation may be expressed thus: $\frac{E}{P}$, where E is the evaporation and P the precipitation. For this comparison it is best to use weekly or 10-day records. With a ratio $\frac{4.59}{1.12}$ on flat land from July 27 to September 2, 1916, there was no danger of forest fires, but during the period July 20 and August 3 following rain the relation on the southwest slope was $\frac{2.21}{0.01}$ during which time the duff dried out to below 10 per cent July 31 and became highly inflammable.

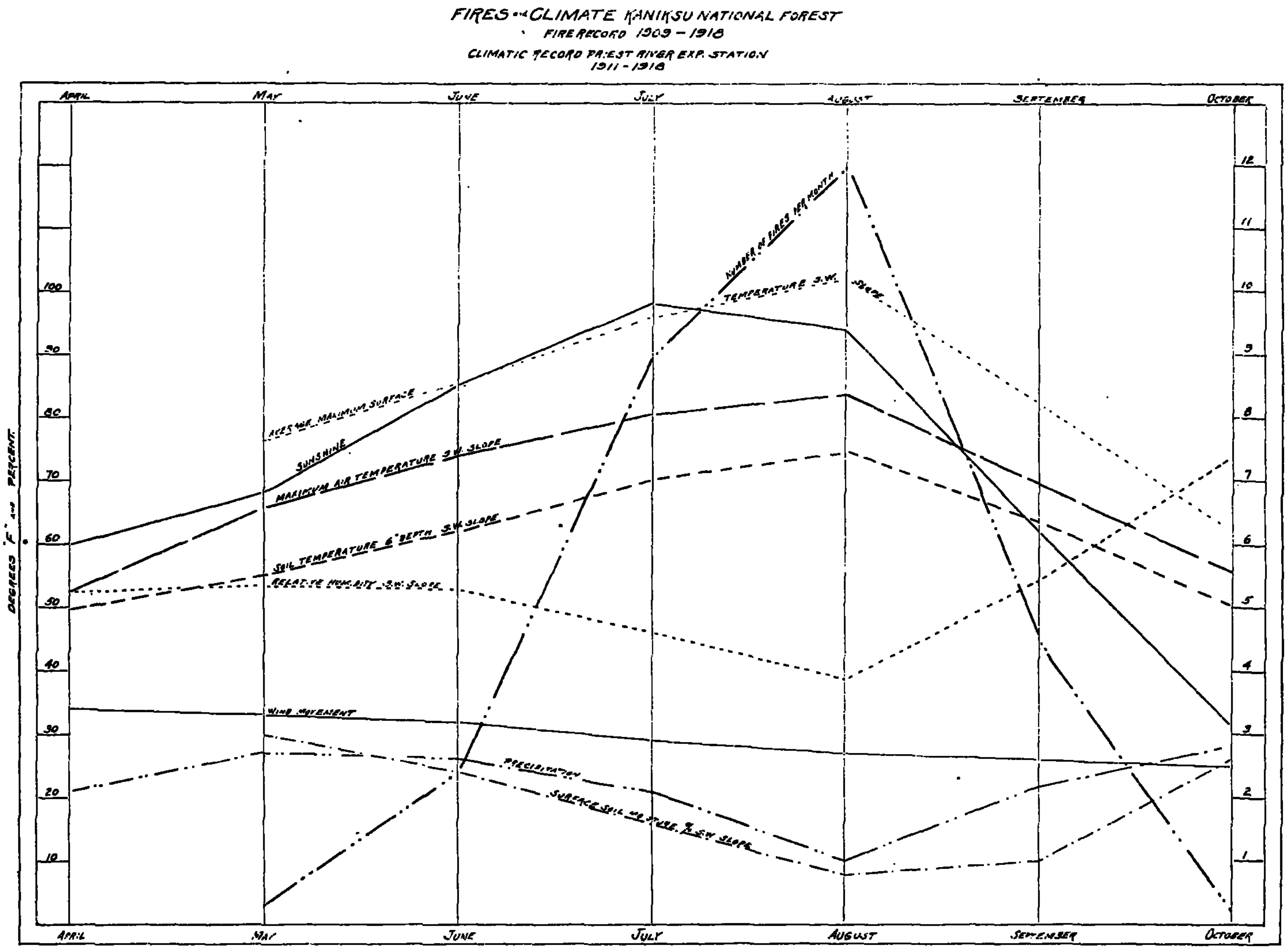

FIG. 12.—Relation between weather and forest fires on the Kaniksu National Forest in north Idaho, 1911-1918, inclusive.

By sampling duff and litter of the forest floor during the summer months and applying burning tests it was found that this material would burn and the fire travel if the moisture content was below 10 per cent measured by its dry weight. Though this is a direct method, it requires much work in sampling, drying, weighing, and calculation, which can not be conducted easily or without considerable equipment.

Another method, which has been suggested by Mr. E. H. Finlyson, of the Canadian Forest Service, holds much promise especially because of its simplicity, ease of observation, and current daily application. It consists in giving certain positive and negative values to all of the climatic elements, such as sunshine, wind, humidity, and rain. By plotting these values for each day, say from the beginning of June, beginning at a red line, designated as neutral, current conditions will be indicated either above or below this line during the summer by giving positive values to sunshine, high temperature, and wind, and negative values to rain or low temperature. The test for accuracy and the giving of correct values to each climatic factor is in returning to the neutral line as soon as there is no fire danger. Several years' record will be needed before the correct values are obtained.

To make this method more effective, one could measure evaporation from free water surfaces and, if desired, measure the intensity of solar radiation by the black and white porous porcelain atmometer cups designed by Dr. B. E. Livingston. It should be stated that maximum air temperatures, the relative humidity at 5 or 6 p. m., and the amount of evaporation will undoubtedly come closer than any other factors of climate in pointing out the seriousness of the situation.

Current records for any one place are of no value unless compared with data for the same place during previous seasons.

Since it has been learned from closer studies that the duff and other material on the forest floor absorb and lose moisture readily, according to the relative humidity of the air, and since the moisture content of this material affects its inflammability very materially, it would seem feasible to prepare standard samples of duff which could be weighed in different parts of the district simultaneously. The moisture content and inflammability of this material may readily be indicated by tabular data prepared at a forest experiment station.

In any event it will be necessary, in order to have a good idea of the current climatic status, to keep close watch of the conditions from month to month, both by instruments, by general observation, and by reports from the field, and to employ some instrumental method for a closer record from day to day and week to week.

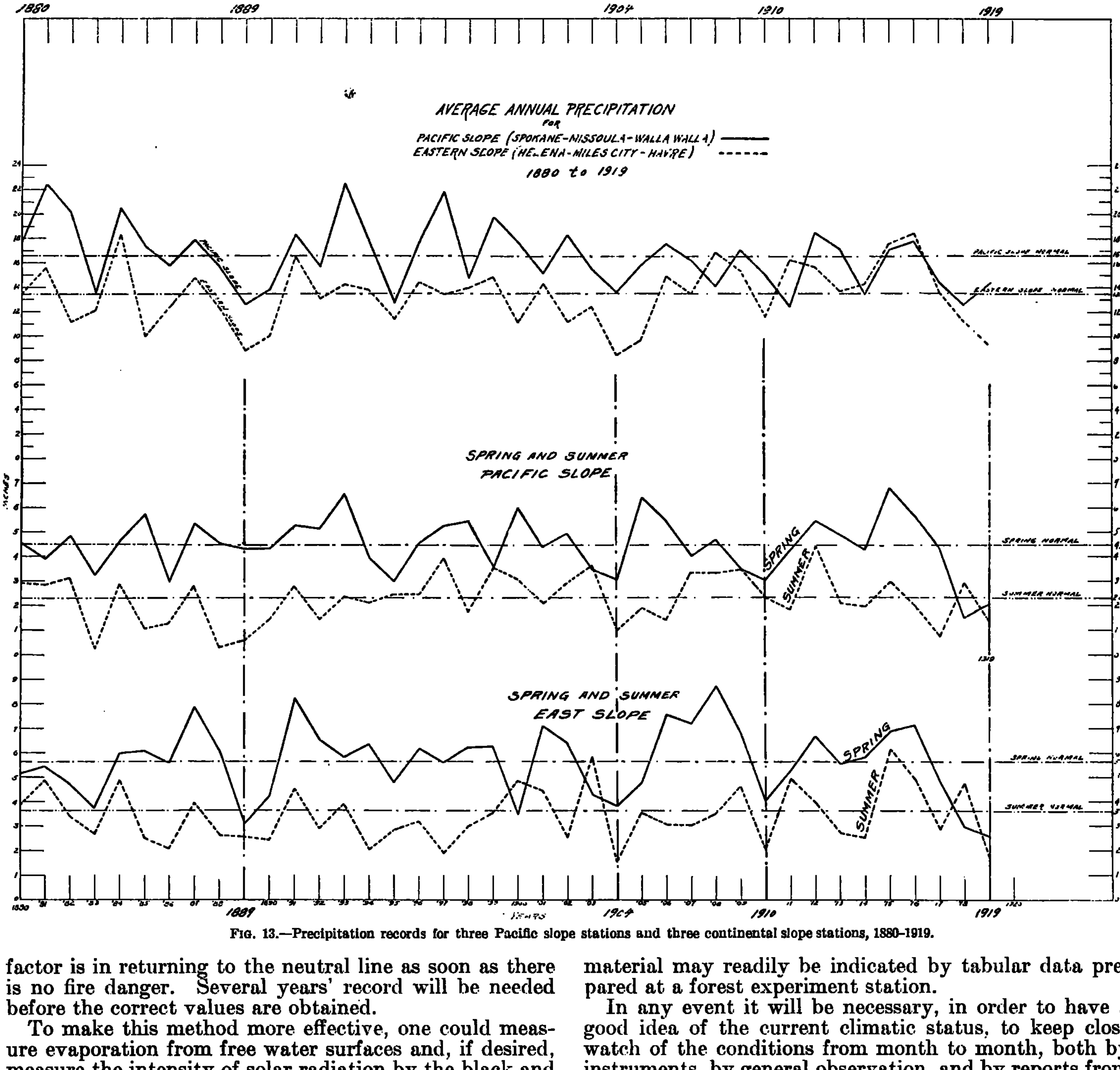

FIG. 13.—Precipitation records for three Pacific slope stations and three continental slope stations, 1880–1919.

SUMMARY AND CONCLUSIONS.

Montana and north Idaho were divided into seven smaller climatic and topographic sections for close comparison between forest fires and climatic records, 1909 to 1919, inclusive.

The comparison brings out that in this region an average of nearly 15 per cent of the area of the national forests has burned over since 1909. The sections west of the Continental Divide have suffered much greater damage than the eastern parts. On the north Idaho forests the fires covered 17 per cent of the area, in northwest Montana 19 per cent, while the eastern sections are all below 8 per cent, some less than 1 per cent. The unusually large area burned over in central Idaho, 43 per cent, is due mainly to the fact that the 1919 fires covered the same ground as the 1910 fires.

The average area per fire in the different sections shows great variations. For north Idaho it is 234 acres, central Idaho 1,154 acres, northwest Montana 281 acres, southwest Montana 130 acres, north central Montana 410 acres, and the rest of Montana less than 100 acres.

This greater fire hazard in the western sections, particularly in Idaho, is due to differences in climatic conditions, particularly rainfall, on the east and west of the Continental Divide. The Idaho sections show high annual and very low summer rainfall, in which respect it conforms to the Pacific coast type of precipitation, while the eastern sections show low annual and comparatively high summer rainfall. In this respect the latter shows its relation to the continental type. Thus the annual rainfall in Idaho averages up to 30 inches, in eastern Montana less than 16 inches; but the July and August rainfall in central Idaho is only 1.40 inches. In eastern Montana it is from 2.43 to 2.92 inches.

The heavy annual precipitation in Idaho gives rise to luxurious forests, with much cedar, hemlock, and fir understory, also much dead and down material. This becomes very dry and highly inflammable in summer on account of the low rainfall and the drying, warm winds coming from the desert region east of the Cascades. These winds blow against the sunny slopes and reach their maximum velocity during the hottest part of the day.

The drier air in the western than eastern sections in summer, and consequently more critical conditions for fires, is shown by an average relative humidity of 25 per cent for Spokane during August, 36 per cent for Kalispell and Yellowstone Park, and 42 per cent at Miles City.

The record shows five years, 1910, 1914, 1917, 1918, and 1919, with serious forest fires, and the remaining five years, 1911, 1912, 1913, 1915, and 1916, fairly free from fires. The bad fire seasons show subnormal spring and summer rainfall, greater than usual amount of sunshine, somewhat higher air temperatures and wind velocities. The average per cent of sunshine at Spokane for July is 77. In July, 1910, it was 88, and in 1919, 89. The average relative humidity at Spokane in August is 25 per cent. In 1910 it was 22 per cent, and in 1919 it was only 16 per cent.

More lightning fires have occurred in central and north Idaho than in the other sections; central Idaho shows a total of 33 per each 100,000 acres in 10 years, north Idaho 23, western Montana 13 each, south-central Montana 2, and southeast Montana 10.8.

The causes of the unusual forest-fire situation during the summer 1919, the worst since 1910, are most likely due to a combination of unusual weather conditions—frozen ground in the fall, so that little moisture went into the ground at the time of melting in spring; much melting of the snow in late December; light winter precipitation; early spring rains most likely fell on the snow in the back woods and therefore did not soak into the ground; very light spring and summer rains. This season, moreover, was the third in a succession of dry summers.

A comparison of climate and fires by months brings out the fact that it is necessary to have at least 2 inches of rainfall for each month in summer to allay forest fires. The average rainfall in the Idaho and western Montana sections are lower than this amount; central Idaho, June, 1.56; July, 0.10; August, 0.70; north-central Montana section shows June, 3; July, 1.72; August, 1.20; south-central Montana, June, 2.46; July, 1.37; August, 1.06 inches.

The most dangerous weather for forest fires occurs at the time of a succession of high-pressure areas over the Pacific Northwest. At such times the air temperature, both maximum and minimum, climbs a little higher each day and the relative humidity reaches very low points.

Climatic records for the last 40 years show a tendency toward periods of very low rainfall each 15 years; the low points were reached 1889, 1904, and 1919; they show also a quite regular drop in the annual rainfall every three years. However, the total annual precipitation does not necessarily mean a bad fire season, for this depends almost entirely upon the summer conditions. It is the combination of low annual, low spring and summer downpour which brings about the unusually bad fire seasons.

The matter of forecasting fire weather in the Pacific Northwest is rendered difficult because there are no fixed points of weather observation to the west of the Pacific coast. Current records, together with past records of fire and climate, must therefore be relied on for the present.

The classification and analysis of the natural conditions set forth in this report are offered, not with the idea that they will help ward off forest fires, but lead to a closer understanding of the natural factors which operate to the destruction of so much valuable timber wealth, dispell certain misleading ideas regarding the relation of climate to forest fires in this region, and serve as a groundwork for later investigations.

DUST SPIRAL NEAR FLAGSTAFF, ARIZONA.

By FERDINAND W. HAASIS.

[Fort Valley Experiment Station, Ariz., March 6, 1922.]

At 1.15 or 1.20 p. m., on June 19, 1920, the writer's attention was attracted by a peculiar sound suggesting an automobile motor. Heard out of doors, the sound resembled the tearing of coarse paper.

Above the forest, due west of the Fort Valley Experiment Station, 9 miles northwest of Flagstaff, a column of tawny dust, the color of the dry soil at that time, was seen traveling in an easterly direction, though with minor deviations, and forming a somewhat undulating band in the general direction of the sun. From below it appeared to be a nearly vertical spiral so close to the sun that the upper part could be seen only with great difficulty. The column was intermittent, sometimes almost wholly disappearing, at which time the characteristic noise subsided also. The height was difficult to estimate; perhaps 500 feet, perhaps 1,000.

When about 500 feet west of the west fence of the station grounds it broke off to the southeast downhill, and whirled around near the back corral. It oscillated on this flat for a time, apparently moving first southeast, then northwest, possibly in a circle, or in other directions. At one time it seemed to be starting to move north or northeast directly toward the station buildings. The